Astronomy & Astrophysics manuscript no. February 1, 2008
(DOI: will be inserted by hand later)

On a probable manifestation of Hubble expansion at the local scales, as inferred from LLR data

Yu.V. Dumin

IZMIRAN, Russian Academy of Sciences, Troitsk, Moscow reg., 142190 Russia
e-mail: `dumin@yahoo.com`, `dumin@cityline.ru`

Received March 11, 2002; accepted Month Day, 2002

Abstract. Processing the data of lunar laser ranging (LLR), whose accuracy now reaches a few millimeters, points to the effect of anomalous increase in the lunar semimajor axis (with an excessive rate 1.3 cm/yr), which cannot be attributed to the well-known tidal exchange of angular momentum between the Earth and Moon. One of the possible interpretations of the above-mentioned anomaly may be the "local" Hubble expansion with $H_0^{(\mathrm{loc})} = 33 \pm 5\,(\mathrm{km/s})/\mathrm{Mpc}$. This small value of the local Hubble constant (about two times less than at intergalactic scales) can be reasonably explained if it is formed only by some kind of an unclumped "dark matter" or "dark energy", while the other kinds of matter experienced a gravitational instability, formed compact objects, and no longer contribute to the formation of Hubble expansion at the local scales.

Key words. Relativity – cosmological parameters – dark matter – celestial mechanics – Earth – Moon

1. Introduction

Precise measurements of the Earth–Moon distance by using the ultrashort laser pulses – the lunar laser ranging (LLR) – are carried out for over 30 years, after the installation of several retroreflectors on the lunar surface in the course of Apollo (USA) and Lunakhod (USSR, in collaboration with France) space missions (e.g. reviews by Dickey et al. 1994; Nordtvedt 1999; Samain et al. 1998). The typical accuracy of these measurements was:

– $\sim$25 cm in the early 1970's,
– 2–3 cm in the late 1980's, and
– a few millimeters at the present time.

LLR works contributed significantly to astrometry, geodesy, geophysics, lunar planetology, and gravitational physics. The most important results related to General Relativity are:

– verification of the Strong Equivalence Principle with accuracy up to $\sim 10^{-13}$,
– determination of the first post-Newtonian parameters in the gravitational field equations,
– detection of the so-called geodetic precession of the lunar orbit, and
– imposing the observational constraints on time variations in the gravitational constant $\dot{G}/G$ with accuracy $\sim 10^{-11}$ per year.

Send offprint requests to: Yu.V. Dumin

2. Using the LLR data for finding the "local" Hubble constant

Despite the considerable advances listed above, there is a long-standing unresolved problem in the interpretation of LLR data – anomalous increase in the lunar semimajor axis (e.g. Pertsev 2000).

In general, such increase is well-known and can be *partially* explained by tidal interaction between the Earth and Moon (e.g. Kaula 1968). Because of the relaxation processes, the tidal bulge is not perfectly symmetric about the Earth–Moon line but slightly shifted in the direction of Earth's rotation (see Fig. 1). As a result, there is a torque moment, which decelerates a proper rotation of the Earth and accelerates an orbital rotation of the Moon; so that the mean Earth–Moon distance increases.

From the angular momentum conservation law

$$I_{\mathrm{E}} \frac{\mathrm{d}}{\mathrm{d}t} \Omega_{\mathrm{E}} + m_{\mathrm{M}} \frac{\mathrm{d}}{\mathrm{d}t} \left(R^2 \Omega_{\mathrm{ME}} \right) = 0 \qquad (1)$$

and the relation between the lunar orbital velocity and its distance from the Earth

$$\Omega_{\mathrm{ME}} = G^{1/2}\, m_{\mathrm{E}}^{1/2}\, R^{-3/2}, \qquad (2)$$

it can be easily found that the rate of increase in the lunar semimajor axis $\dot{R}$ is related to the rate of deceleration of the Earth's rotation $\dot{T}_{\mathrm{E}}$ by the well-known formula:

$$\dot{R} \;=\; k\, \dot{T}_{\mathrm{E}}\,, \qquad (3)$$

$$\begin{aligned} k \;&=\; 4\,\pi\, G^{-1/2}\, I_{\mathrm{E}}\, m_{\mathrm{E}}^{-1/2}\, m_{\mathrm{M}}^{-1}\, R^{1/2}\, T_{\mathrm{E}}^{-2} \\ &=\; 1.81{\cdot}10^{5}\ \mathrm{cm/s}, \end{aligned} \qquad (4)$$

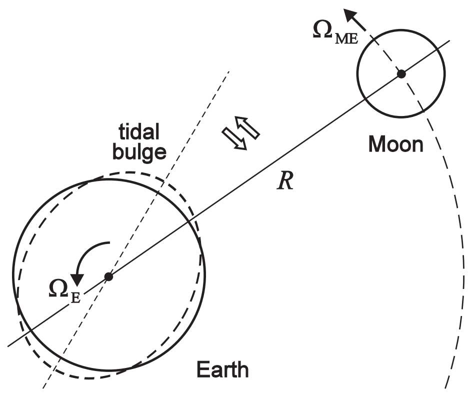

Fig. 1. A scheme of tidal exchange of angular momentum between the Earth and Moon.

where $\Omega_{\rm E}$ and $T_{\rm E}$ are the angular velocity and period of the proper rotation of the Earth, $\Omega_{\rm ME}$ is the angular velocity of orbital rotation of the Moon about the Earth, R is the distance between them[1], $I_{\rm E}$ is the Earth's moment of inertia, $m_{\rm E}$ and $m_{\rm M}$ are the terrestrial and lunar masses, and G is the gravitational constant.

As follows from *telescopic observations* of the Earth's rotation with respect to the distant objects, collected over the last 300 years, $\dot{T}_{\rm E}^{\rm (tel)} = 1.4{\cdot}10^{-5}$ s/yr (Pertsev 2000). So, according to Eq. (3), $\dot{R}^{\rm (tel)} = 2.53$ cm/yr. On the other hand, immediate measurements of the Earth–Moon distance by *LLR technique* give an appreciably greater value $\dot{R}^{\rm (LLR)} = 3.82$ cm/yr (Dickey et al. 1994).

The most of attempts to explain the anomaly $\Delta\dot{R} = \dot{R}^{\rm (LLR)} - \dot{R}^{\rm (tel)} = 1.29$ cm/yr were based on accounting for some additional geophysical effects (e.g. secular changes in the Earth's moment of inertia $I_{\rm E}$). Unfortunately, they did not lead to a satisfactory quantitative agreement with observations.

Yet another promising interpretation of the above-mentioned anomaly $\Delta\dot{R}$, from our point of view, is Hubble expansion in the local space environment, which should contribute to $\dot{R}^{\rm (LLR)}$ but will not manifest itself in $\dot{R}^{\rm (tel)}$. As follows from the standard relation $\Delta\dot{R} = H_0^{\rm (loc)} R$, the "local" Hubble constant should be

$$H_0^{\rm (loc)} = 33 \pm 5\,{\rm (km/s)/Mpc}. \qquad (5)$$

3. Discussion

At first sight, the Hubble constant given by Eq. (5) seems to be erroneous, since it equals only about one-half the commonly-accepted value at intergalactic scales. Nevertheless, it can be reasonably interpreted if the local Hubble expansion is formed only by some kind of an *unclumped* "dark matter" or "dark energy", uniformly distributed in the Universe (such as Λ-term, "quintessence", inflaton-like scalar field, and so on); while the other kinds of matter experienced a gravitational instability, formed compact objects, and are no longer able to make their contributions to the rate of Hubble expansion at the local scales.

Besides, apart from any theoretical arguments, the recent observations (e.g. by Ekholm et al. 2001) revealed that a linear "quiescent" Hubble flow begins at least from the distances ∼1–2 Mpc, i.e. an order of magnitude less than was usually expected before. This fact was also interpreted by Chernin et al. (2001) as a manifestation of some unclumped dark matter.

So, the LLR technique, which was used so far only in solar-system studies, may also become a valuable tool for solving the cosmological problems, because it enables us either to measure a local rate of Hubble expansion or to impose an upper limit on this quantity (Dumin 2001a).

Of course, a cosmological nature of the anomalous increase in the Earth–Moon distance is not reliably established by now. It may be also caused merely by some geophysical artefacts. To distinguish between these two possibilities, it would be very interesting to seek a similar effect in some artificial satellite system, which does not suffer from geophysical uncertainties (Dumin 2001b). The suitable objects may be the space-based laser interferometers projected for searching the gravitational waves, such as LISA (e.g. Bender et al. 1998).

Acknowledgements. I am very grateful to Yu.V. Baryshev, P.L. Bender, A.D. Chernin, E.V. Derishev, C. Hogan, S.M. Kopeikin, S.M. Molodensky, M. Tinto, and A.V. Toporensky for valuable discussions and critical comments, as well as to D.P. Kirilova and V.D. Kuznetsov for various help in the course of work.

References

Bender, P., Brillet, A., Ciufolini, I., et al. 1998, LISA: Laser Interferometer Space Antenna for the detection and observation of gravitational waves. Pre-Phase A Report, 2nd edn. (Garching: Max-Planck-Institut für Quantenoptik)
Chernin, A., Teerikorpi, P., & Baryshev, Yu. 2001, Adv. Space Res., in press [`astro-ph/0012021`]
Dickey, J. O., Bender, P. L., Faller, J. E., et al. 1994, Sci, 265, 482
Dumin, Yu. V. 2001a, Geophys. Res. Abstr., 3, 1965
Dumin, Yu. V. 2001b, preprint [`astro-ph/0112236`]
Ekholm, T., Baryshev, Yu., Teerikorpi, P., Hanski, M. O., & Paturel, G. 2001, A&A, 368, L17
Kaula, W. M. 1968, An Introduction to Planetary Physics: The Terrestrial Planets (New York: J. Wiley & Sons)
Nordtvedt, K. 1999, Class. Quant. Grav., 16, A101
Pertsev, B. P. 2000, Izvestiya: Phys. Solid Earth, 36, 218
Samain, E., Mangin, J., Veillet, C., et al. 1998, A&AS, 130, 235

[1] Within the accuracy required here, we can neglect the ellipticity of the lunar orbit.